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MOISTURE CONDITIONS IN WALLS AND CEILINGS OF A SIMULATED OLDER --ETC(U)
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MOISTURE CONDITIONS IN WALLS AND CEILINGS OF A SIMULATED OLDER HOME DURING WINTER

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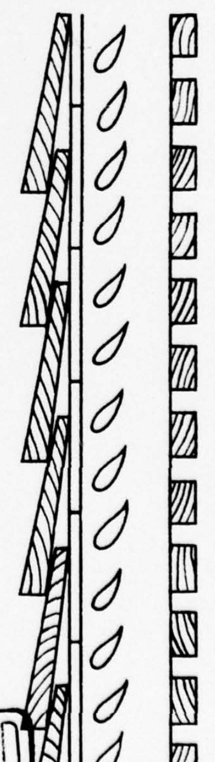
U.S. DEPARTMENT OF AGRICULTURE
FOREST SERVICE
FOREST PRODUCTS LABORATORY
MADISON, WIS.



SUMMARY

Many older homes, built without insulation and consequently without vapor barriers, have had insulation added ~~in recent years~~. In many such homes no moisture problem has become apparent; in others paint has peeled, etc. or extractives have run down the face of the siding. Even where there is no ~~evidence of high~~ external evidence, moisture levels within walls, moisture buildup in ~~the~~ wall and ceiling insulation can reduce its effectiveness.

To obtain information on moisture in insulated walls and ceilings which lack vapor barriers, a small exposure unit was instrumented. Indoor relative humidity conditions resulting from normal household activities were simulated in part of the building. The remainder of the interior space was maintained ~~at 35 percent~~ relative humidity. Walls tested incorporated the usual plaster with oil-base paint, unmodified and with two types of remedial modification (two coats of aluminum paint, exterior 1-in. vents). Three depths of insulation were used in the ceiling.

~~The~~ test data showed that insulation added to walls of an older home subject to the climate at Madison, Wis., may not cause visible moisture problems where mechanical humidification is not used. However, where a relative humidity of 35 percent is maintained in the house, condensation in the walls is likely without remedial measures. Increasing depth of ceiling insulation resulted in a slight increase of moisture in the insulation, but good ventilation kept moisture at acceptable levels.

This information should be useful to homeowners and home-improvement contractors.

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MOISTURE CONDITIONS IN WALLS AND CEILINGS OF A SIMULATED OLDER HOME DURING WINTER.

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U.S. Department of Agriculture

INTRODUCTION

Many houses built prior to 1940 were constructed without insulation in walls and ceiling, so insulation has been blown into wall cavities and attic spaces in an effort to save energy and increase comfort. This addition of insulation has the effect of moving the zone in which condensation occurs toward the inside face of the wall or ceiling, and thus sometimes results in moisture condensing in the insulation during cold weather. A membrane that has a low permeability to water vapor is applied to the warm face of walls and ceilings in new construction, but such a membrane is difficult to add after construction. This membrane is called a vapor barrier because it retards the movement of water vapor from the warm side of a building component into the insulation; thus a buildup of moisture in the insulation is prevented.

In many structures where insulation has been added without benefit of a vapor barrier, no damage from moisture buildup has become apparent. However, there is no way of knowing the exact conditions inside the wall cavity without removing the covering materials. In other structures, condensation in the walls has resulted in serious problems of paint peeling or extractives from sheathing or siding running down the face of the exterior wall. Regardless of whether condensation presents visible problems, research has shown that moisture does reduce the thermal efficiency of insulation.[2] Also, when the moisture content (MC) of wood reaches high levels decay can occur with consequent deterioration of the structure.

Some corrective measures have been taken where serious condensation occurs, and preventive measures are sometimes applied. Observations have been made of existing houses incorporating such measures, but no test data are available which can be related to specific conditions.

A small exposure unit was instrumented to monitor moisture levels in walls and ceilings without vapor barriers under specific indoor moisture conditions. Although weather conditions and combinations of materials used in construction vary greatly, data from this study suggest what may happen in similar cases.

CONSTRUCTION AND TEST CONDITIONS

A 16- by 24-foot building near Madison, Wis., previously used to study moisture distribution in walls of new construction,[3] was used for this study (fig. 1). The building had been constructed with conventional floor and roof framing, but vertical support was provided by

[1]Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[2]Adams, Ludwig. 1974. Thermal Conductivity of Wet Insulations. ASHRAE J. 16(10): 61 - 62.

[3]Duff, J. E. 1968. Moisture Distribution in Wood-Frame Walls in Winter. Forest Prod. J. 18(1): 60 - 64.

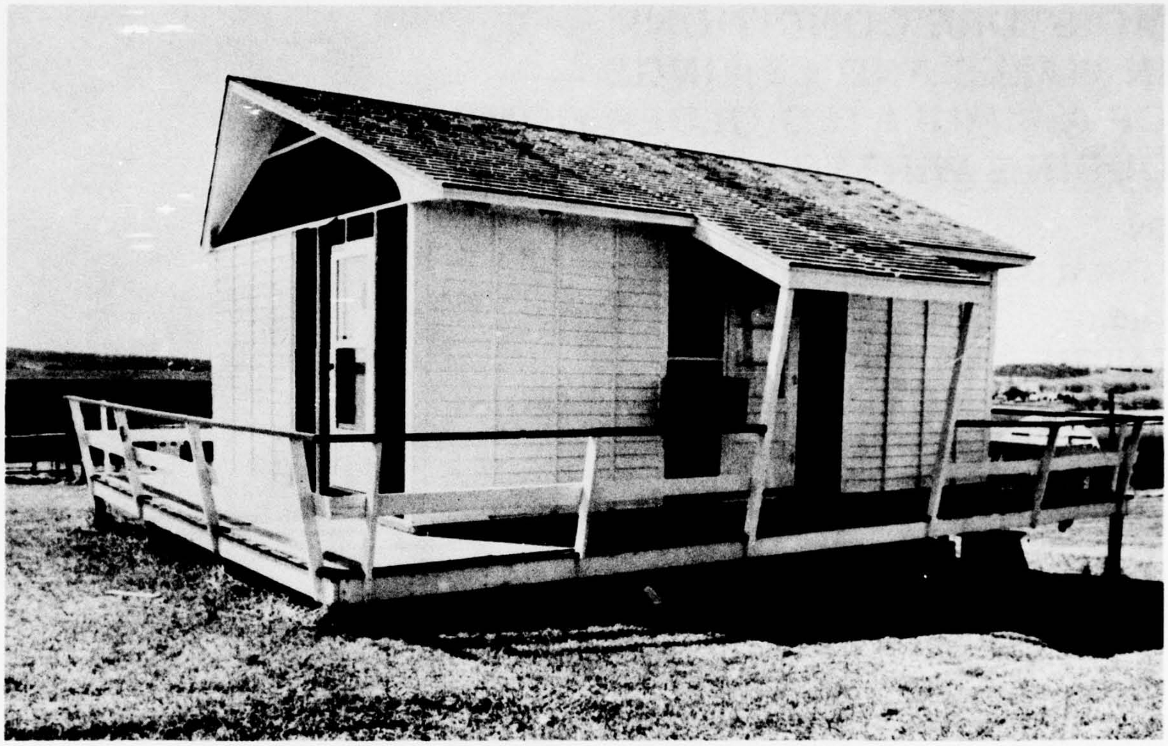

Figure 1. -- The U.S. Forest Products Laboratory test house located on the exposure site near Madison, Wis.
(M 144 205-3)

nominal 4- by 4-inch posts at 8-foot spacing to permit the use of seven 8- by 8-foot removable wall panels. Each of the seven wall panels was divided into four spaces with nominal 2- by 4-inch studs, resulting in 28 test spaces (fig. 2, table 1). A nominal 1- by 6-inch board coated with aluminum paint was placed adjacent to each stud and extended to the outside to prevent moisture transfer between spaces and the sheathing or siding covering each space.

Sheathing was of 1- by 8-inch boards spaced slightly to simulate older construction in which the boards often shrink and leave a slight gap. A 15-pound asphalt-impregnated sheathing paper was applied over the sheathing boards, and 1/2- by 6-inch beveled siding was added. Siding was given two coats of oil-base paint. The interior was finished with gypsum lath and plaster and given two coats of oil-base paint. An older house would have wood lath, but both the wood lath and the gypsum lath have very high permeability, so this substitution should have no effect on moisture transfer through the walls. Identical construction was used for all spaces in this study.

Variables for the study included indoor humidity conditions, orientation of test walls (north, south, east, or west), interior paint, and the presence or absence of exterior ventilation for the wall cavity.

All three 8- by 16-foot rooms (fig. 2) in the test building were heated to 72° F ±2° F by electric heaters. The east room (panels N-1, E-1, and S-1) simulated an existing older house with insulated walls but no remedial measures for condensation control. Differing remedial measures for condensation control were applied on the three exterior walls (panels N-3, W-3, and S-3) of the west room. Spaces 3 and 4 in each of these panels received two coats of aluminum paint over the plaster. Spaces 1 and 2 were ventilated to the outside by inserting 1-inch-diameter vents through the siding and sheathing near the top and bottom of each space.

Each of the two end rooms was supplied by atomization with the same amount of moisture each day to simulate moisture introduced

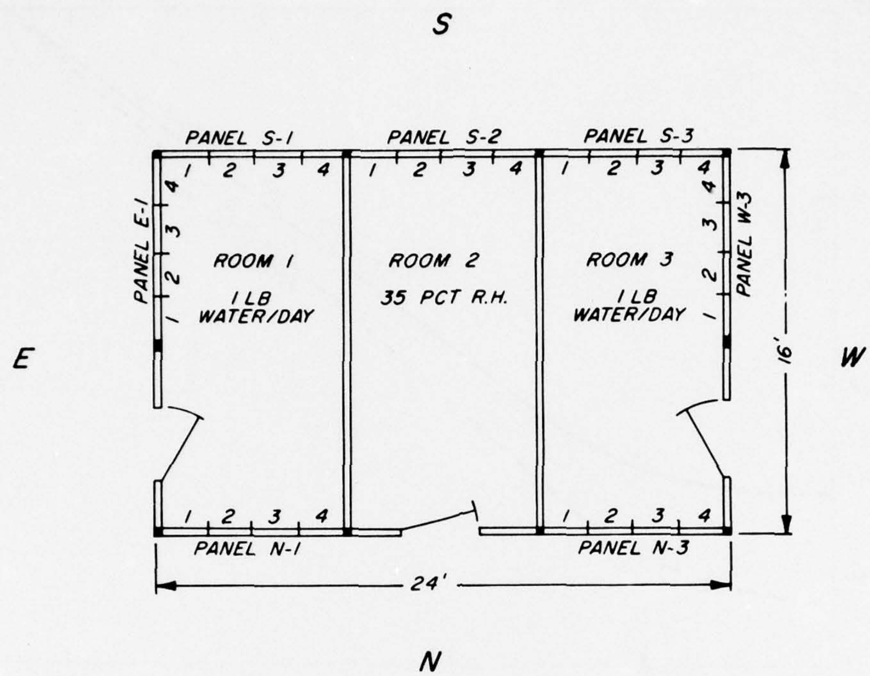

Figure 2. -- Plan of the test building.
(M 144 897)

Table 1. -- Location and variables for monitored test spaces

Number of test spaces	Location	Panel code	Humidity conditions
	NO PREVENTIVE MEASURES		
4	Room 1, north	N-1	Varying
4	Room 1, south	S-1	Varying
4	Room 1, east	E-1	Varying
2	Room 2, south	S-2	35 pct RH
	TWO COATS ALUMINUM PAINT		
2	Room 3, north	N-3	Varying
2	Room 3, south	S-3	Varying
2	Room 3, west	W-3	Varying
1	Room 2, south	S-2	35 pct RH
	TWO 1-INCH EXTERIOR VENTS		
2	Room 3, north	N-3	Varying
2	Room 3, south	S-3	Varying
2	Room 3, west	W-3	Varying
1	Room 2, south	S-2	35 pct RH
28 Total			

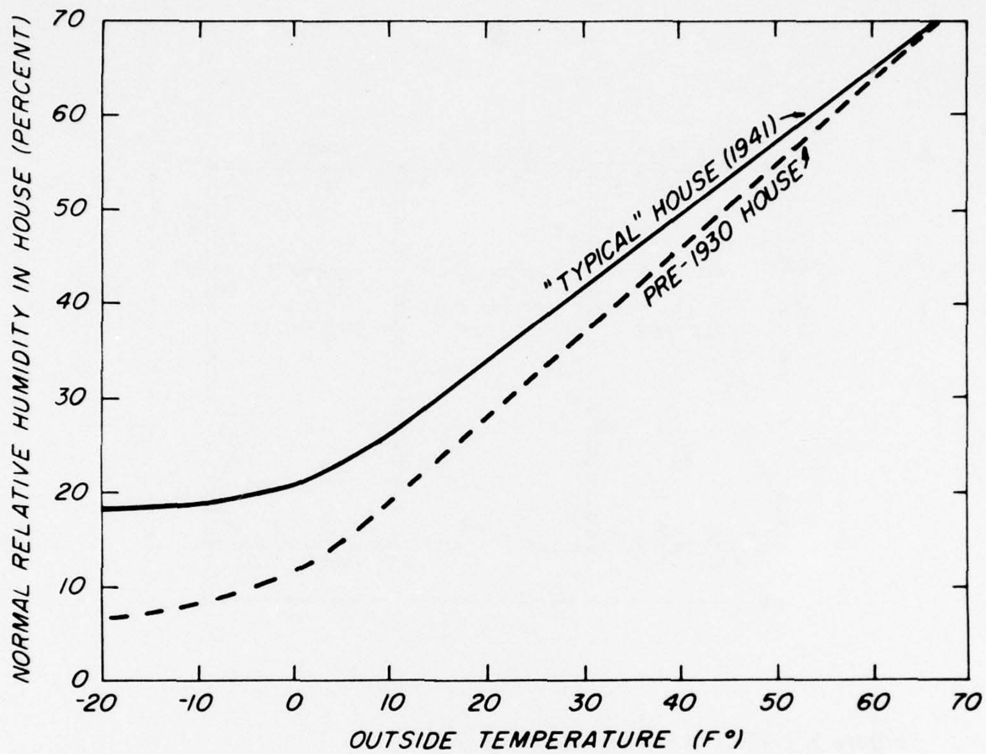

Figure 3. -- Relation of normal humidity within a house to outside temperature, modified from Teesdale's 1947 study.
(M 144 898)

by normal daily activities in homes with no mechanical humidification. An attempt was made to use an amount of water equivalent to the usual moisture introduced by a family, proportioned to the size of rooms in the test house. However, this resulted in overhumidification because no allowance was made for air changes caused by opening doors or use of heating equipment and appliances. Therefore, to determine the correct amount of daily moisture to be added, relative humidity curves (fig. 3) were used. These curves were developed through observation by Teesdale and documented in 1947.[4] Teesdale's curves for a "typical house" (i.e., in 1947) and for a pre-1930 house should approximate humidity levels in what are today considered "older homes." It was found that the addition of 1 pound of water per day to each room resulted in a relative humidity between the two curves of figure 3. This amount of humidification was continued throughout the test season.

The center room was maintained at 35 ± 5 percent relative humidity by a commercial humidifier. An access door and electrical panel were located on the north wall of this room, so only the south wall was available for experimental wall sections (panel S-2). Of the four spaces in panel S-2, two had no remedial measures, one had 1-inch-diameter exterior vents near the top and bottom, and one was protected with two coats of aluminum paint on the plaster.

Attic space was partitioned with 6-mil polyethylene film to prevent moisture transfer between the spaces over each of the three rooms. No vapor barrier was used in any of the ceilings. End rooms had 4-1/2-inch glass fiber batt ceiling insulation. End attic spaces were ventilated by continuous 2-inch wide eave vents and a triangular vent at each gable.

The center room had 2-1/4-inch glass fiber batts over one-half the ceiling and 6-3/4-inch glass fiber batts over the other one-half. Center attic space was ventilated by continuous 2-inch eave vents and a roof vent near the ridge.

[4]U.S. Forest Products Laboratory. 1962. Remedial Measures for Building Condensation Difficulties. Forest Prod. Lab. Rep. No. 1710, Madison, Wis.

Table 2. -- Weather conditions during test period[1]

Month	Low temperature	High temperature	Degree days	Mean degree days
	° F	° F		
December 1974	+6	+41	1,179	1,330
January 1975	-6	+53	1,329	1,473
February 1975	-14	+43	1,220	1,274
March 1975	-8	+51	1,198	1,113
April 1975	+12	+78	714	618
Total for test period			5,640	5,808

[1]Data from the Madison Weather Service Office, National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

Weather conditions for the period covered by this study (December 1974 through April 1975) are shown in table 2. These data indicate that the period covered by the study was not unusual for a winter in Madison, Wis. Degree days for the period were about 3 percent below the mean.

INSTRUMENTATION AND MEASUREMENTS

The method used for measuring moisture within the wall and ceiling areas is detailed in the following paragraphs.

MOISTURE CONTENT

The moisture content of small wood sensors was measured at six locations in each test space (fig. 4). Actual installations are shown in figures 5, 6, and 7. In addition to these, MC was also measured in wood probes placed in the attic on the upper and lower side of the ceiling insulation. The wood MC brought about by the outside air was measured with probes placed in protected spaces immediately adjacent to the siding. Altogether, 179 locations were measured for wood MC with small wood-type sensors but MC of actual components was not determined. The air within the rooms was monitored for relative humidity using a sling psychrometer.

A sensor capable of remote reading was required because most of the locations for moisture measurement were relatively inaccessible. The system used employed a calibrated wood sensor element and a commercial moisture meter. Construction and details of the operation of this sensor are given by Duff.[5] The probes were calibrated in humidity rooms to an accuracy of ±2 percent MC over a relative humidity range of 35 to 90 percent which was considered sufficiently accurate for this study. This corresponds to a MC in the wood probe of 7.0 to 20.5 percent. Determination of MC beyond these limits was less accurate due to difficulties in measuring extreme ranges of resistance. Also, beads of condensed water were often present on probe surfaces at probe readings of 20.5 percent or higher.

TEMPERATURE MEASUREMENT

The MC as indicated by the probe requires correction only for temperature changes of 10° F or more. Inside room temperature was used for correcting the moisture probes located immediately adjacent to the interior wall lining. Outside air temperature was used to correct the probes immediately beneath the siding. For the moisture probes within the wall between the insulation and sheathing, actual thermocouple measurements were made for each probe. Placement of a probe and its associated thermocouple for temperature is shown in figure 6.

All temperatures were measured using Type T (copper-Constantan) thermocouples and an ice bath reference.

[5]Duff, J. E. 1966. A Probe for Accurate Determination of Moisture Content of Wood Products in Use. U.S. Forest Serv. Res. Note FPL-0142. Forest Prod. Lab., Madison, Wis.

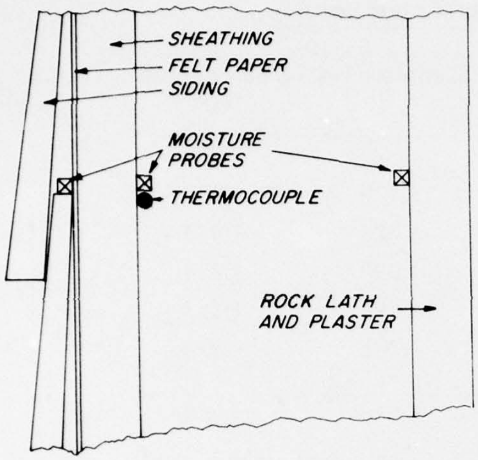

Figure 4. -- Cross section of stud space showing location of moisture probes and thermocouples. Probes were located at both one and seven feet from the floor.
(M 144 899)

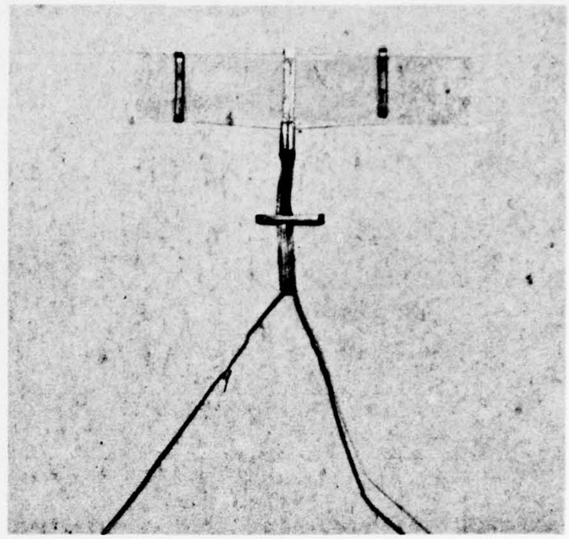

Figure 5. -- Moisture probe attached to surface of rock lath.
(M 144 310)

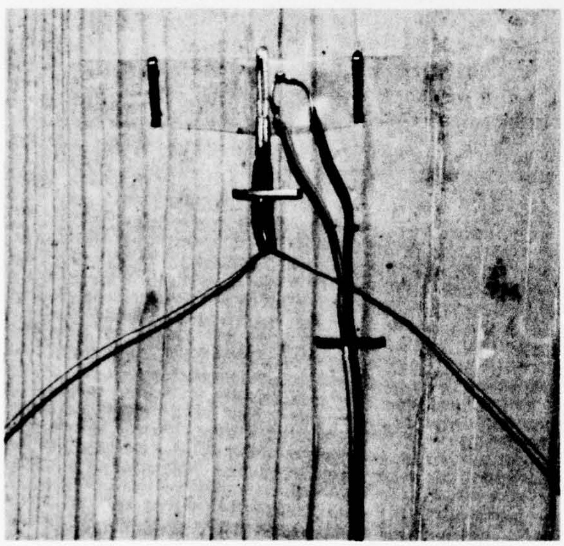

Figure 6. -- Moisture probe and thermocouple attached to interior surface of sheathing board.
(M 144 309)

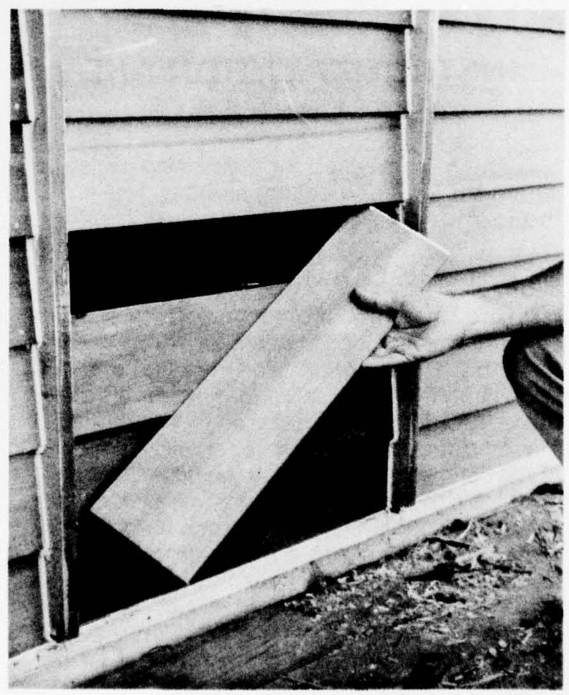

Figure 7. -- Moisture probe located immediately beneath siding.
(M 142 642-9)

DATA RECORDING AND CONVERSION

The system for monitoring MC consisted of the moisture probes connected through a scanner to a commercial moisture meter, digitizer, and teletype. Thermocouple readings were fed to a multichannel low voltage digital data system and printed on paper tape.

Raw data from each moisture sensor were first converted to MC readings via a calibration curve and then corrected to actual MC for the temperature associated with the specific probe. The last step corrected the probe readings for species of wood used in the probe -- giving a final, true MC. The corrected data were then keypunched for computer plotting.

Readings were taken at about 1 p.m. once a week from December 2, 1974, to April 24, 1975.

RESULTS AND DISCUSSION

Some variations in moisture level occurred between wall sections of the same construction even where the interior environmental conditions were alike. Some of this variation is probably due to slight differences in materials and construction tolerances. Another major influence was the location of wall sections within each room. Corners were generally colder because heat did not circulate into these areas well. The wind direction also influenced the moisture conditions in the wall.

Readings within wall sections of the same construction were generally consistent despite small variations. Agreement was adequate to evaluate the effect of indoor relative humidity and remedial measures on the buildup of moisture in the wall cavity and at the siding-sheathing interface.

Values of wood MC greater than 20.5 percent were observed in the probes. However, because percentage readings over this level are of questionable accuracy, values above 20.5 percent were not plotted. Readings above 20.5 percent generally indicated the presence of beads of condensed water on probe surfaces and thus a risk of decay if sustained. The structure is in danger at any sustained MC over 20.5 percent, so that the amount 20.5 percent is exceeded is not highly relevant. However, the length of time wood remains above 20.5 percent is important and is recorded in the data. The MC through all of the wall sections is presented in the appendix and one representative plot for each type of wall section is included within the text (figs. 8,9, and 10).

The sections which follow discuss MC in walls with no remedial measures, in walls incorporating remedial measures, and finally in ceiling insulation.

WALLS WITH NO REMEDIAL MEASURES

The MC measurements for walls with no remedial measures show a contrast between simulated "normal" humidity and mechanical humidification (35 pct RH).

In the center room where relative humidity was maintained at 35 percent, the MC at the siding-sheathing interface of panel S-2 rose above 20 percent early in the winter and remained high until early April (fig. 8A). The MC at the sheathing-insulation interface was below 20 percent throughout the winter.

The MC of unmodified test sections under varying "normal" humidity (panels S-1, N-1, and E-1) is shown in figures 8B, C, and D. Moisture in the south wall (panel S-1) remained below the 20.5 percent level throughout the winter, but increased sharply at the sheathing-siding interface about the middle of April. Because the outdoor temperature at that time was warm, there was not a high vapor pressure differential driving moisture out through the walls. The increased MC in panel S-1 appeared to be caused by extremely humid outdoor conditions.

On the north side of the building (panel N-1), the MC at the sheathing-siding interface was consistently high and often rose above 20 percent for short periods of time.

The MC in the east wall (panel E-1) remained well below the 20 percent level throughout the winter.

WALLS WITH REMEDIAL MEASURES

The MC readings after ventilating wall cavities or applying aluminum paint to the plaster suggests the effect of these remedial measures.

Vented Cavities

The ventilated space in the south wall of the center room (panel S-2) had frequent moisture levels above 20.5 percent at the siding-sheathing interface (fig. 9A), and at or near 20.5 percent at the sheathing-insulation interface. The MC at the insulation-plaster interface varied between 8 and 12 percent, which indicates the ventilation in the space moved the dewpoint temperature toward the indoor face of the wall. The moisture level at

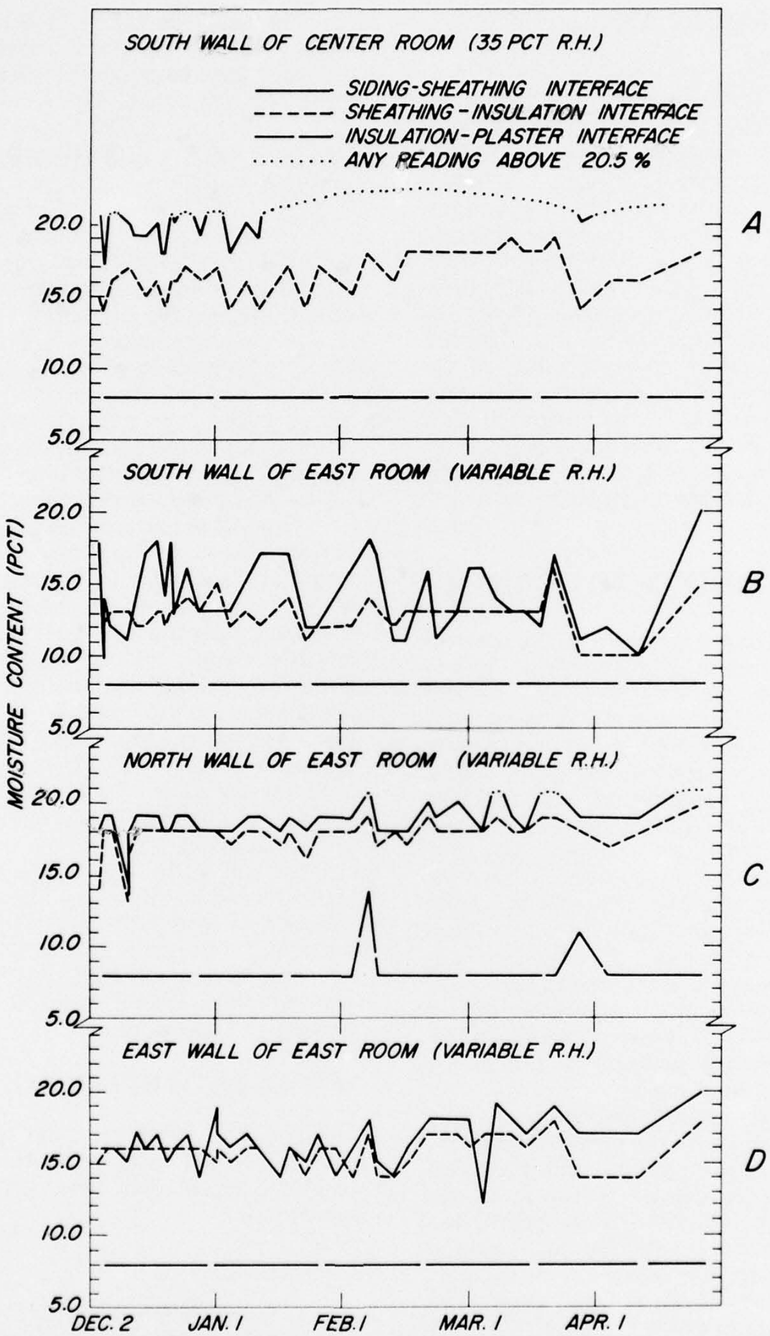

Figure 8. -- Moisture conditions through typical wall sections which incorporate no remedial measures.
(M 144 900)

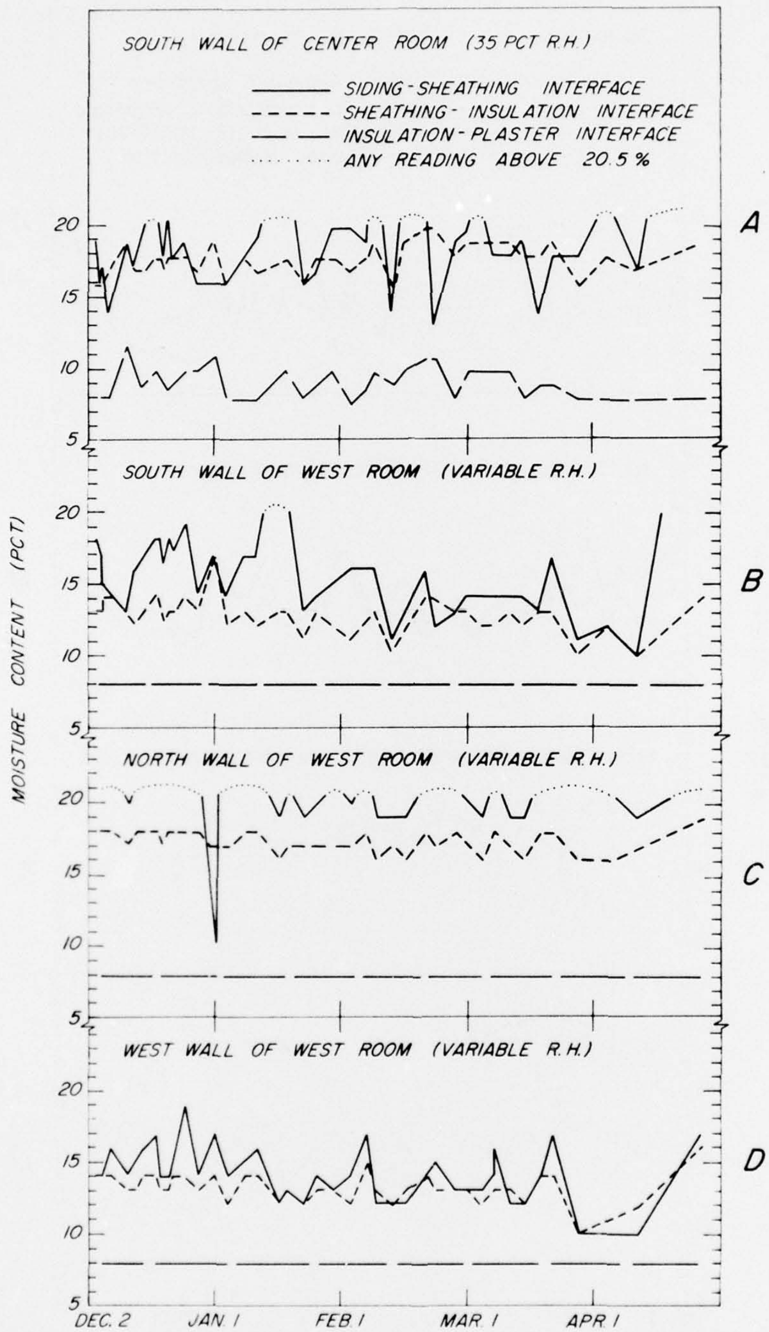

Figure 9. -- Moisture conditions through typical wall sections with 1-inch diameter vents at top and bottom of wall.
(M 144 902)

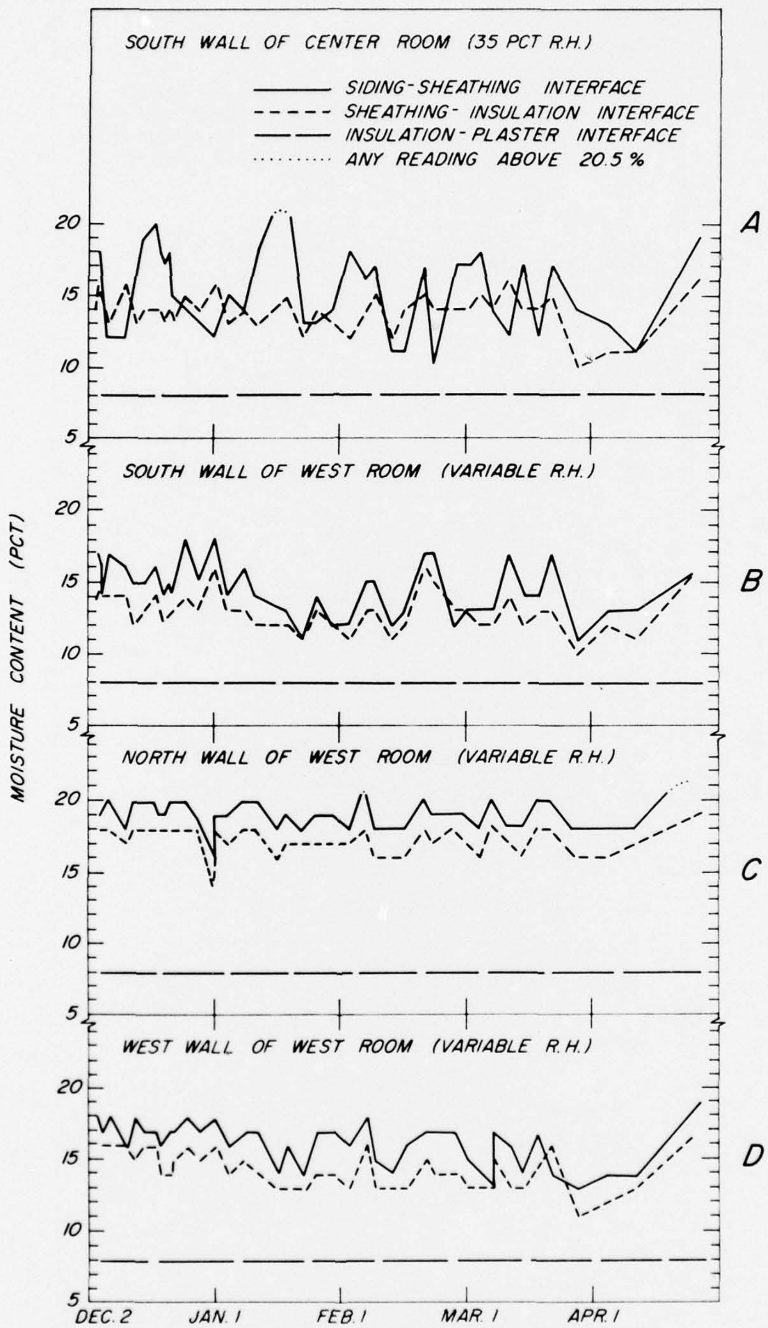

Figure 10. -- Moisture conditions through typical wall sections with aluminum paint on plaster.

(M 144 901)

the sheathing-siding interface was not as consistently high as in the wall with no treatment, but moisture levels at other points in this wall were higher, suggesting a greater rate of heat loss. The vents may prevent some paint failures, but this advantage is offset by higher levels of moisture nearer the warm face of the wall.

Moisture levels at the siding-sheathing interface in ventilated spaces in the west room (figs. 9B, C, and D) were above 20.5 percent all winter in the north wall (panel N-3). The south wall (panel S-3) had moisture levels below 20.5 percent except for one cold period in January. There was no apparent advantage of the ventilated space over no remedial treatment in the north and south walls. The MC in the ventilated spaces in the west wall (panel W-3) remained below 20.5 percent throughout the winter. A possible explanation is that the prevailing wind from the west forced ventilation through the vented spaces and thus kept them dry.

Aluminum Paint on Plaster

The aluminum-painted wall in the center room performed much better than the other two types of walls under the same conditions (fig. 10A). The MC remained below 20 percent except for a limited period of extreme cold in January.

In the west room where relative humidity was allowed to fluctuate with outdoor temperature, the moisture level stayed well below 20 percent in the south wall and the west wall (panels S-3 and W-3), and only once reached 20 percent in panel N-3 of the north wall (figs. 10B, C, and D).

CEILINGS

The MC data from probes in three different thicknesses of ceiling insulation suggest the extent of potential problems under both normal humidity and mechanically induced humidity.

The moisture level at the ceiling-insulation interface was a constant 10 percent for all conditions of construction. Moisture readings at the top of the insulation over both east and west rooms followed the same general trend, ranging from 10 to 20 percent (fig. 11).

The MC levels at the top of the 2-1/4 and 6-3/4 insulation in the ceiling of the center room (fig. 12) were the same near the beginning and end of the winter. However, during most of the season, moisture readings at the top of the deeper insulation were consistently higher by 1 to 3 percent. Even with the deeper insulation the MC stayed below 20 percent because good ventilation was provided. These

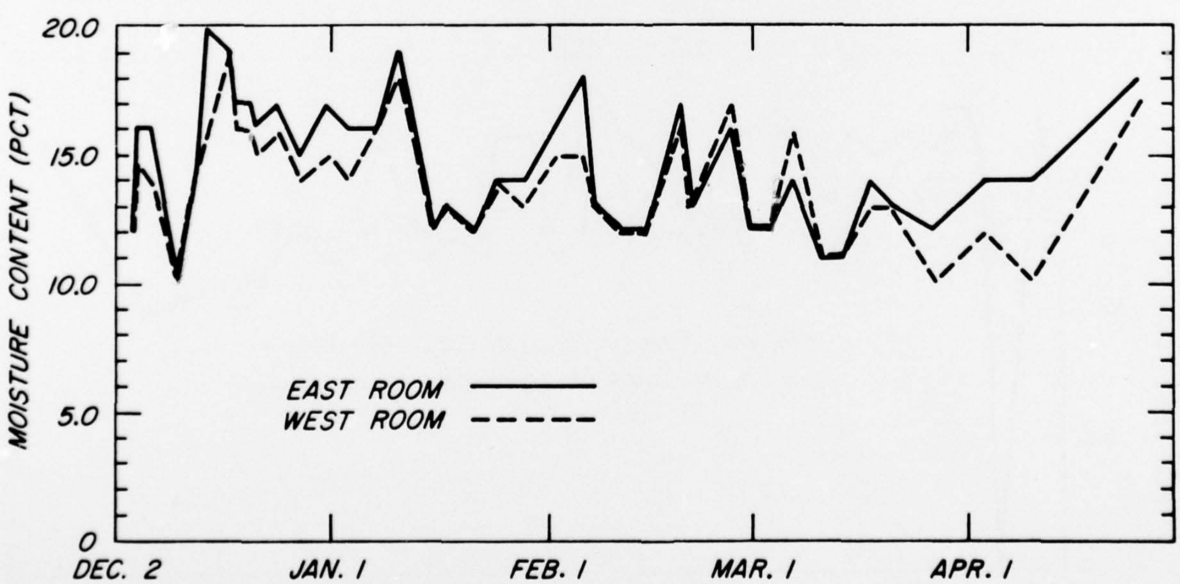

Figure 11. -- Moisture content at top of ceiling insulation over east and west rooms.
(M 144 891)

ceiling readings illustrate the increased importance of good ventilation as depth of insulation is increased.

GENERAL OBSERVATIONS

No exterior finish problems were noted in spite of the high MC at the siding-sheathing interface at some locations. This could partially be attributed to good paint application and a limit of one winter of observation. Finish problems may develop over a longer period of time.

FINDINGS

The following findings relate only to the climatic conditions of Madison, Wis. Where winters are more severe, condensation problems will be greater. For milder winters, condensation problems will be less. A 20.5 percent MC in the wood probes is cited as critical because beads of condensed water are generally present on surfaces; wood is considered in danger of decay at this moisture level, and thus the structure is in danger.

1. Where no mechanical humidification was used, simulating a house of older construction with insulation but no vapor barrier, MC of most walls at the siding-sheathing interface reached levels above 20.5 percent only for short periods of time.

2. Vents placed near the top and bottom of a wall space only slightly reduced the MC at the sheathing-siding interface. They did result in higher MC near the warm face of the wall because the cold air had the effect of moving the dewpoint temperature closer to the warm face.

3. Two coats of aluminum paint on the plaster kept the MC of wall components below 20.5 percent most of the time even where indoor relative humidity was maintained at 35 percent.

4. Where no vapor barrier was used in the ceiling, increased depth of insulation resulted in an increase of MC at the top of the insulation; however, good ventilation prevented a buildup of high moisture conditions.

CONCLUSIONS

The addition of insulation to walls of an older house with no vapor barrier subject to the climate at Madison, Wis., may not cause moisture problems; however, it is a marginal situation and will vary with tightness of the house and habits of the occupants. Even where no visible problems occur, moisture decreases the thermal efficiency of insulation. Where mechanical humidification is used to maintain

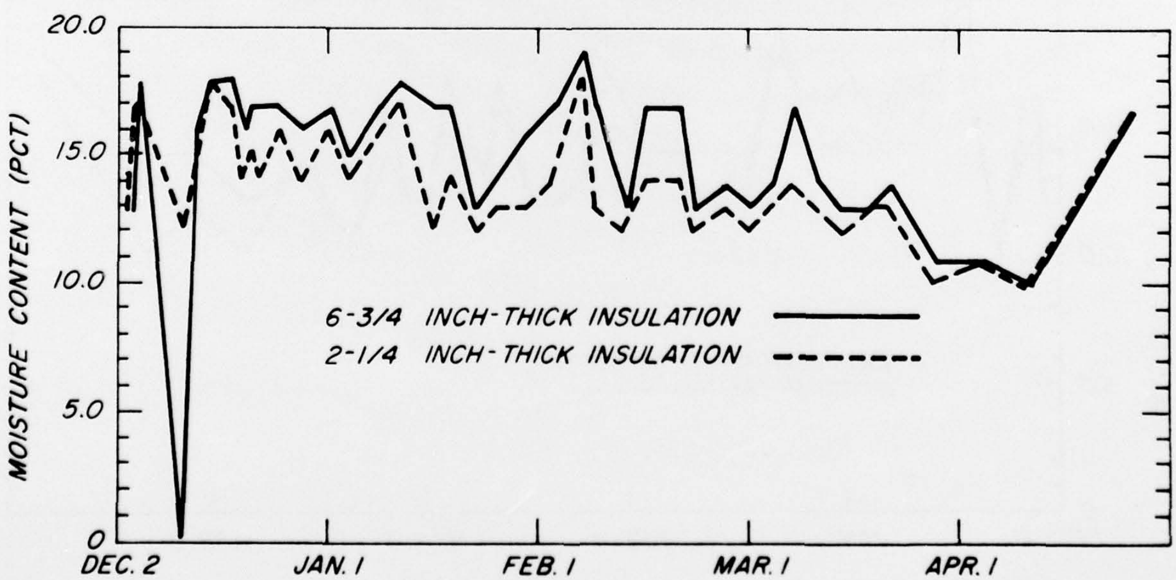

Figure 12. -- Moisture content at top of ceiling insulation over center room.
(M 144 892)

35 percent relative humidity or higher, critical levels of moisture condensation in the walls are likely.

One-inch-diameter vents installed near the top and bottom of a stud space provide little help in keeping the wall cavity dry except on the windward side of the building where wind forces ventilation through the cavity. The vents do keep moisture levels lower at the sheathing-siding interface, which may help prevent paint peeling.

Two coats of aluminum paint applied over the plaster creates an effective vapor barrier for the climate conditions at Madison, Wis., even where mechanical humidification is used.

An increase in depth of ceiling insulation does result in an increase in the moisture level near the top of the insulation, making good attic ventilation more critical.

APPENDIX

Moisture Content Plots for All Test Spaces

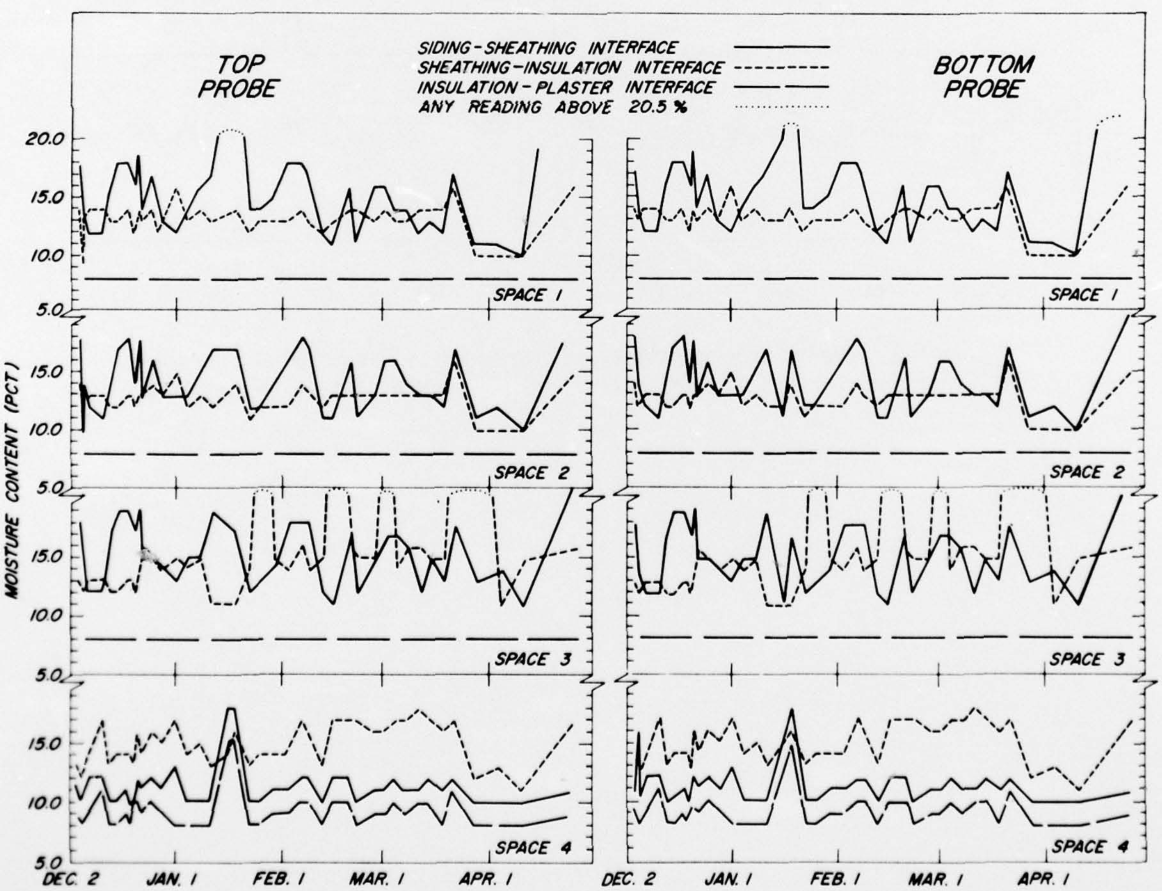

Figure A-1. -- Moisture content through cross section of wall panel S-1 (south wall of east room). The RH was varying; there were no remedial measures.

(M 144 908)

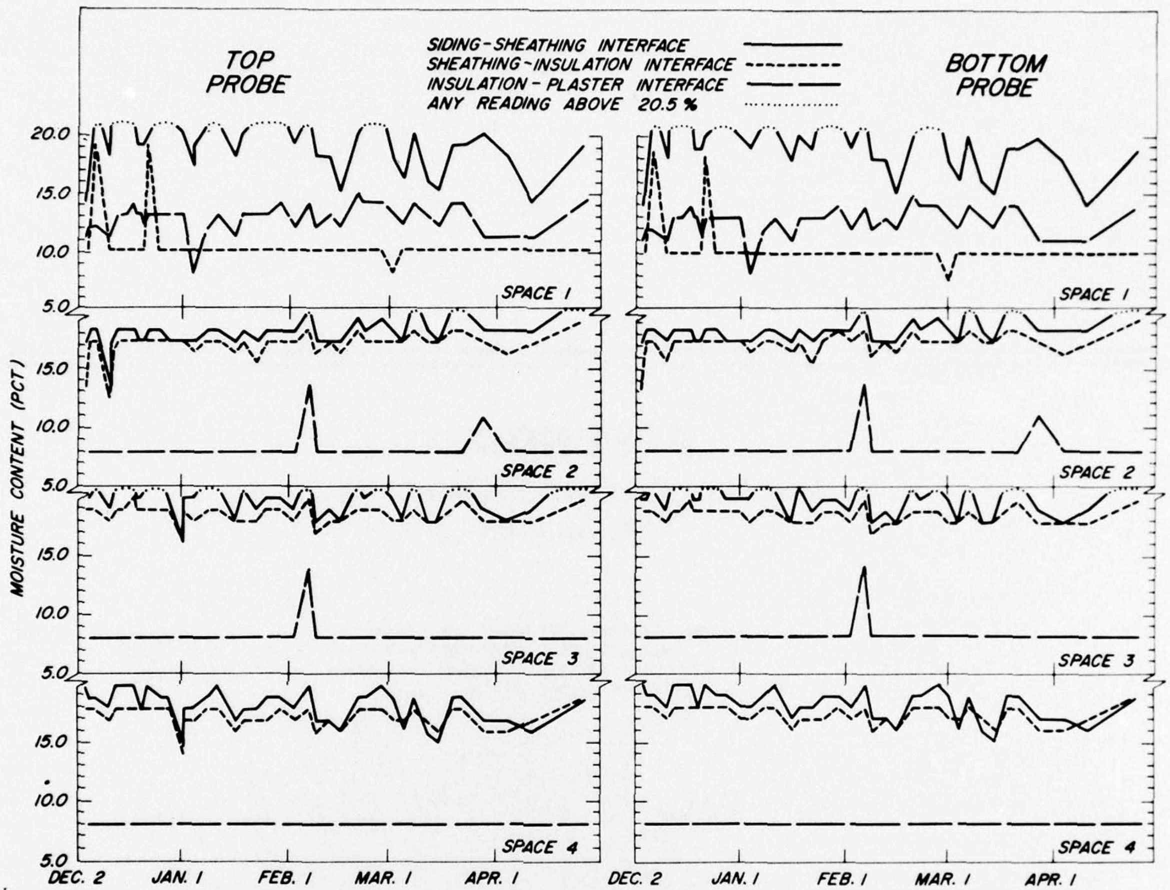

Figure A-2. -- Moisture content through cross section of wall panel N-1 (north wall of east room). The RH was varying; there were no remedial measures.

(M 144 907)

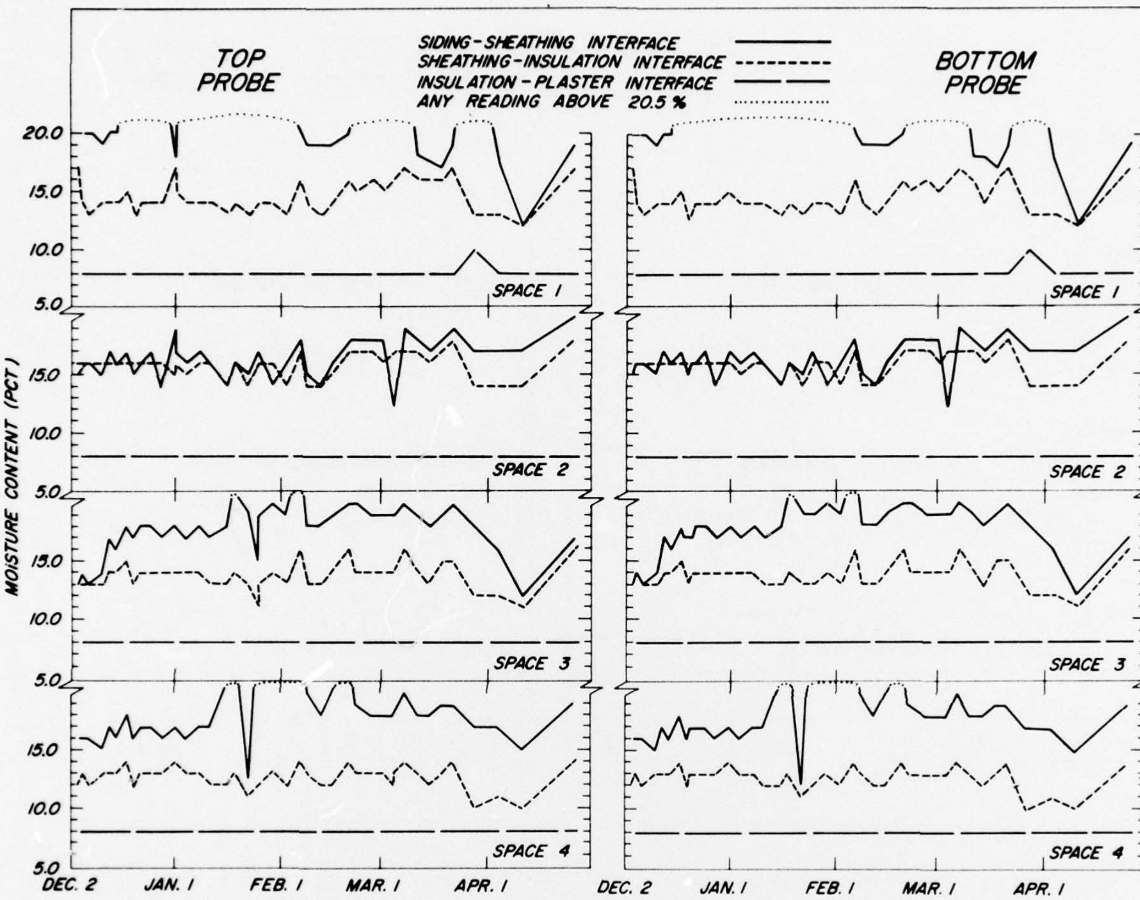

Figure A-3. -- Moisture content through cross section of wall panel E-1 (east wall of east room). The RH varied, and there were no remedial measures.

(M 144 903)

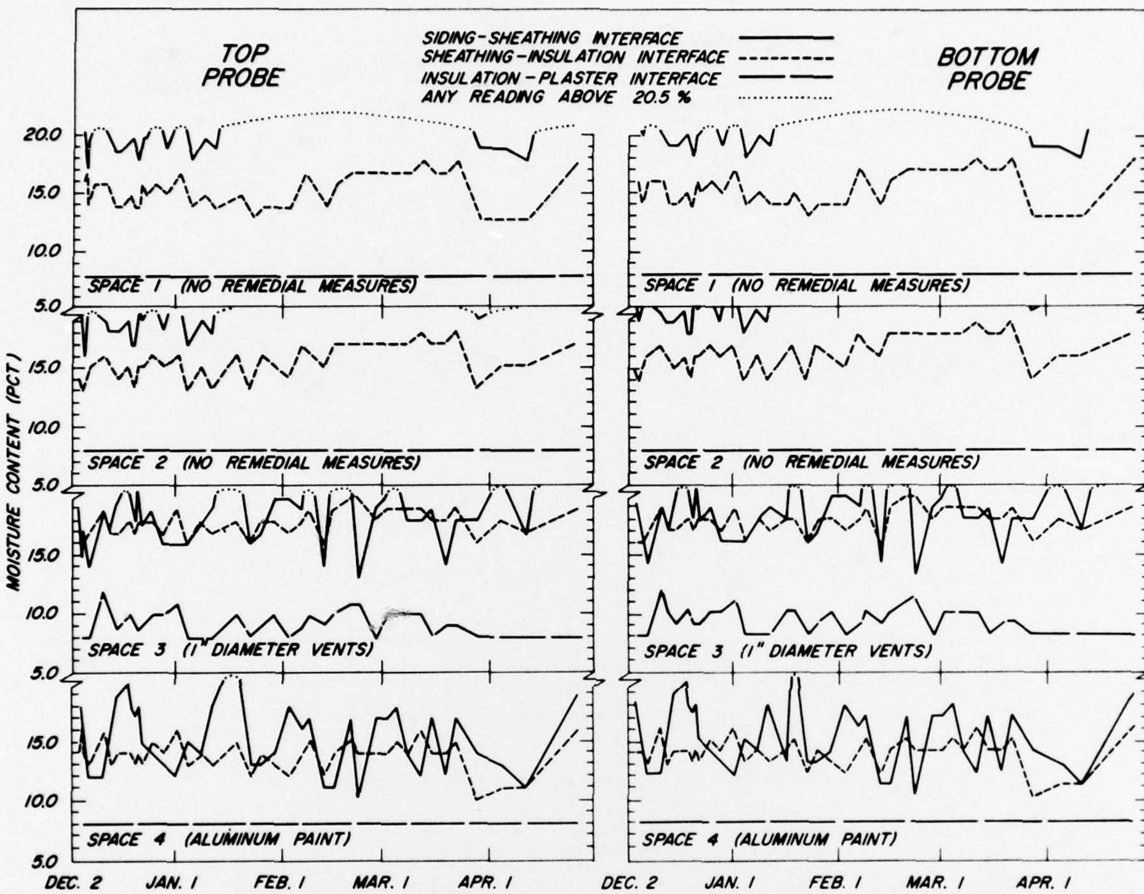

Figure A-4. -- Moisture content through cross section of wall panel S-2 (south wall of center room). The RH was 35 percent; remedial measures are as noted.

(M 144 906)

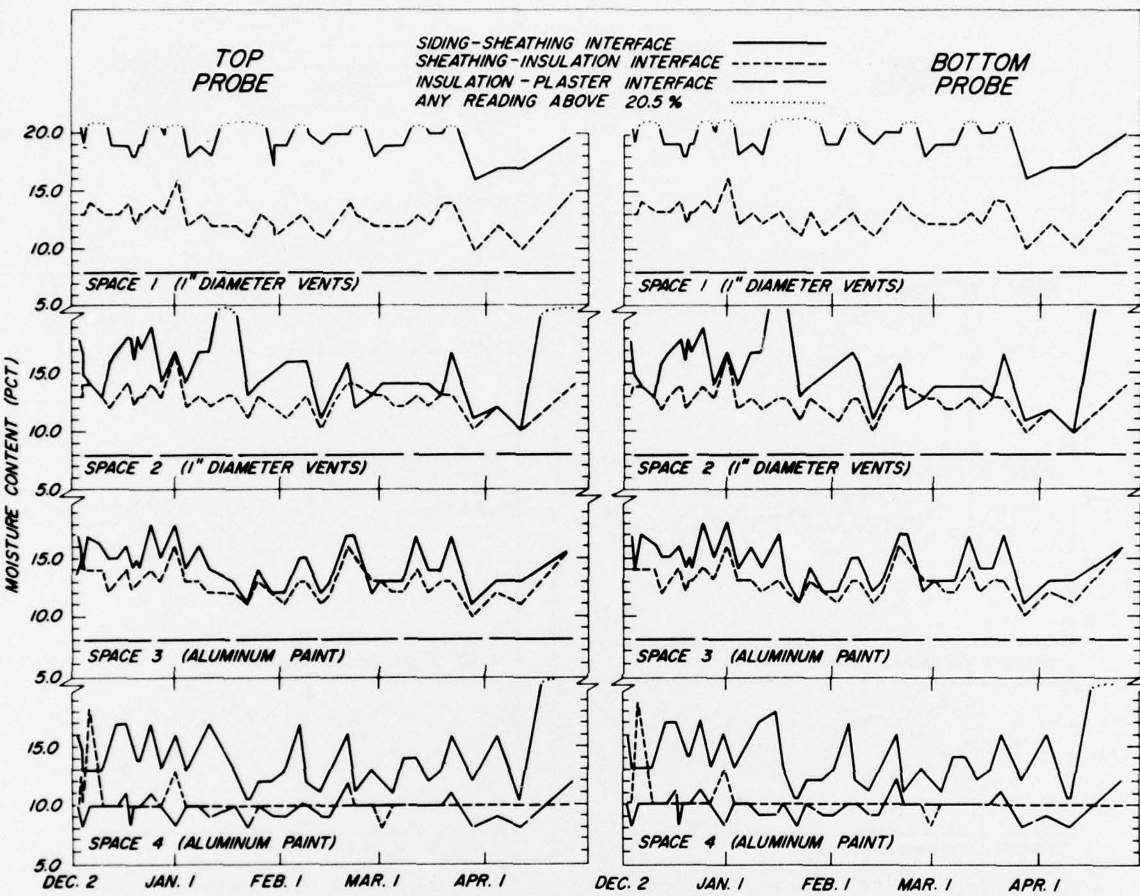

Figure A-5. -- Moisture content through cross section of wall panel S-3 (south side of west room). The RH was varying; remedial measures as noted.
(M 144 905)

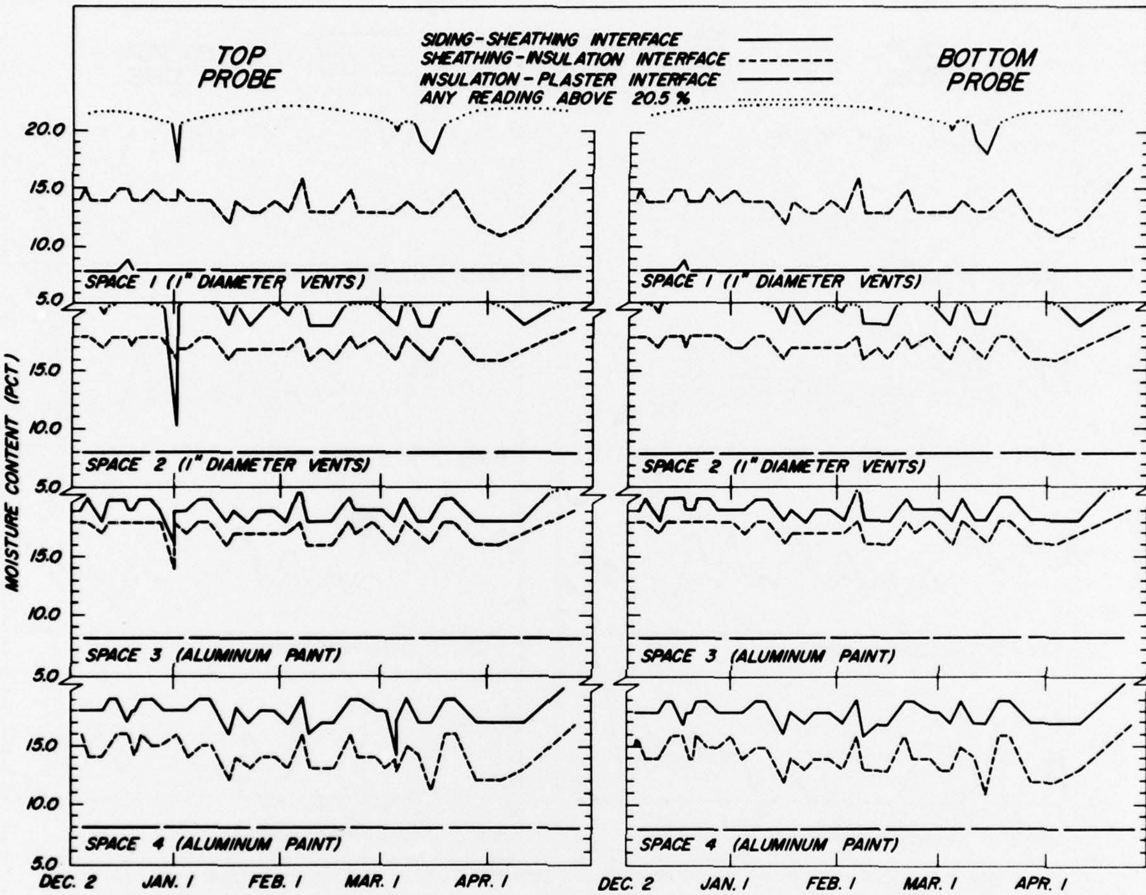

Figure A-6. -- Moisture content through cross section of wall panel N-3 (north wall of west room). The RH was varying; remedial measures as noted.
(M 144 909)

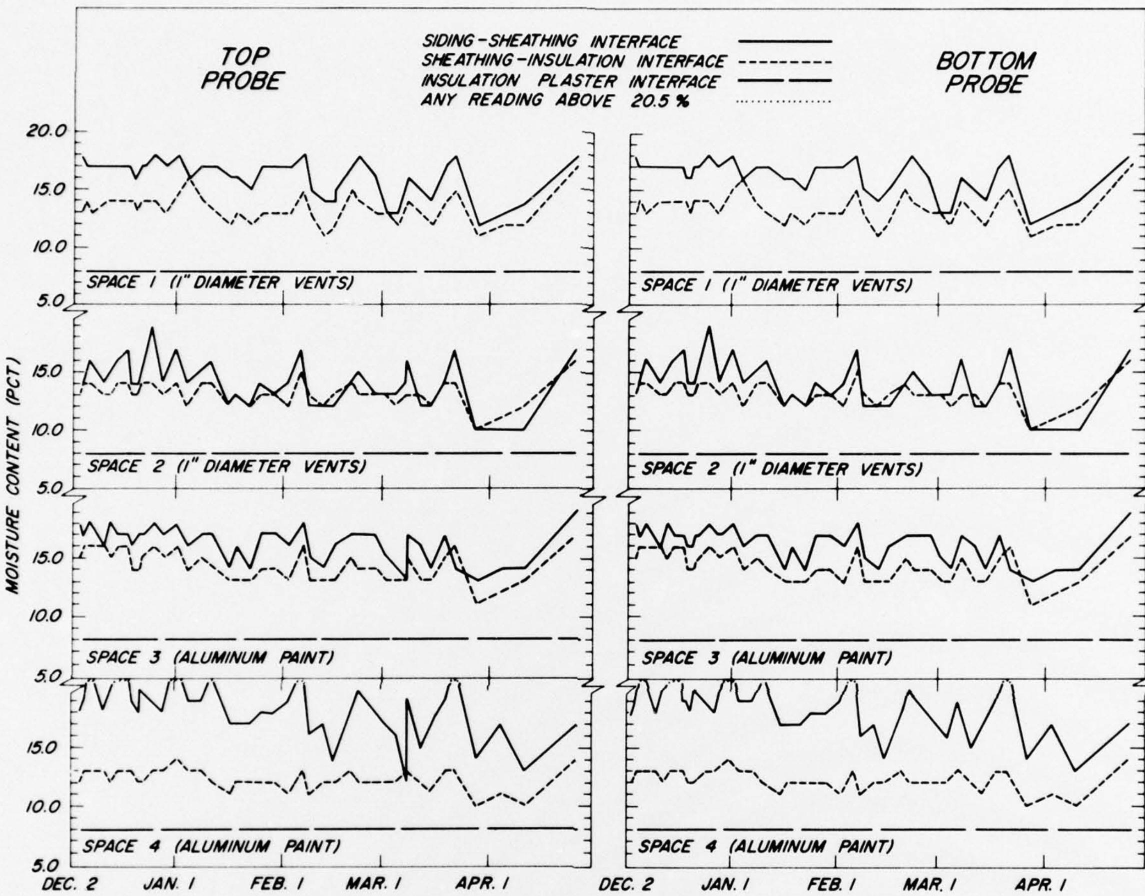

Figure A-7. -- Moisture content through cross section of wall panel W-3 (west wall of west room). The RH was varying; remedial measures as noted.

(M 144 904)

U.S. Forest Products Laboratory.

Moisture conditions in walls and ceilings of a simulated older home during winter, by Gerald E. Sherwood, Madison, Wis., FPL, 1977.
19 p. (USDA For. Serv. Res. Pap. FPL 290).

Investigates moisture conditions in older homes lacking vapor barriers which have had insulation added to walls or ceilings.

KEYWORDS: Condensation, humidity, insulation, moisture, vapor barrier.

U.S. Forest Products Laboratory.

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